actions of its competitors can sometimes affect the level of those costs,[22] the mere existence of competitors has no effect on the firm's costs. However, under spectrum sharing arrangements, a firm's costs depend critically upon the number of competitors in the market, the technology they use, and the services they supply. Thus adoption of non-exclusive licenses for WBPR LMS systems greatly increases the uncertainty associated with an investment in research and development, and, all else equal, this would slow the rate of innovation in the WBPR LMS market.

D. Expanding the Number of Competitors Will Not Result in More Technological Diversity

The Commission's interim rules and the proposed rules in the NOPR intentionally provide a great deal of technical flexibility to service providers. The technology for WBPR LMS systems is changing over time; different licensees currently use different systems with different technical characteristics which serve customers in different ways. Thus under the interim rules, technology progressed along different paths, and there is no reason to think that adoption of similarly flexible permanent rules would eliminate that technological diversity.

1. The number of WBPR LMS providers in each market does not limit technical diversity or the number of firms supplying R&D.

Co-channel separation does not reduce technological diversity. Under the Teletrac proposal, only two WBPR LMS systems can compete in the 900 MHz bands in a single geographic market, but both systems would have an incentive to innovate

[22]For example, expansion of a competitor which shifted outward the market demand for an input would increase the market price for that input.

or to adopt any technologies that lowered costs or expanded capacity. Even if the same two WBPR LMS firms competed in every geographic market in the U.S., each system in each area would have an independent incentive to provide the most profitable service at the lowest cost, even if that service or technology differed across geographic markets. As each new geographic market develops, firms must decide which technology to implement. As these markets are generally not contiguous, the choice of technology for any firm can differ across markets. Indeed, one might expect there to be technical differences that might cause a firm to prefer one technology in (e.g.) small markets and another technology in large markets or one technology in dense areas with tall buildings and another in sparse areas. Under the Commission's flexible rules, competition among technologies--even for WBPR LMS systems in the 900 MHz band--would not be constrained by a limitation on the number of firms in each market.

This point is critical and easy to miss. Co-channel separation limits <u>each geographic market</u> to two WBPR LMS competitors in the 900 MHz bands.[23] Given the number of geographic markets in the U.S. and overseas, there is no limit to the number of competitors from the perspective of inducing research, development, and technical change. Of course, Teletrac does not design or manufacture its own equipment; it purchases equipment from multiple vendors (such as Mitsubishi and Tadiran) who in turn supply equipment to providers of other telecommunications services. Competition among WBPR LMS system providers and equipment

[23]But, of course, there are other competing sources of LMS services besides WBPR LMS service in the 900 MHz bands.

manufacturers for discovering better and lower-cost technology and equipment is unaffected by limitations on the number of WBPR LMS providers in any single geographic market.

Cellular mobile telephone provides an example of technical progress and diversity in a duopoly market structure.[24] At present, cellular technology is based on analog radio technology. Some markets are currently reaching saturation, however, and a great deal of research and development has been undertaken to find ways to make more efficient use of the given allocation of spectrum. While cellular providers have invested heavily in such research and development, many of these recent technological

telephone market, despite the co-channel separation requirements that limit each geographic market to two participants.

2. Technical diversity would be limited by the requirement that services share spectrum.

Opening the 900 MHz band to multiple users on a shared basis would not necessarily increase the diversity of service and technology. As shown in the Engineering Analysis of Cochannel Pulse-Ranging LMS Systems,[25] Section IX and in Dr. Jackson's Affidavit,[26] it is difficult for different technologies to share spectrum efficiently, particularly if their pattern of use of spectrum is very different. Since sharing requires close coordination of the technical parameters of the services offered among competitors, it would be difficult (for example) to accommodate a new service or technology whose technical characteristics were very different from that of the incumbents. Whatever advantage multiple providers would have in theory in supplying diversity would be offset in practice by the conforming requirements imposed by the need to share and coordinate use of the spectrum. Moreover, some LMS services, e.g., personal location services, require more bandwidth than others, so that restriction of the bandwidth available to a WBPR LMS provider to less than the full 8 MHz may actually reduce the availability of services.

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[25]Prof. Raymond Pickholtz, Engineering Analysis of Cochannel Pulse-Ranging LMS Systems (June, 1993) (hereinafter "Pickholtz Study").

[26]Affidavit of Dr. Charles L. Jackson, Attachment to the Reply of North American Teletrac and Location Technologies, Inc., FCC File Nos. 347483-347502, April 8, 1993, pp. 8-10.

3. Diversity of WBPR LMS services in the 900 MHz band is not necessary to provide LMS service diversity to customers.

Service diversity must be measured in the eyes of the customer. Consumers derive no additional satisfaction if a diversity of needs are met by a diversity of services in a particular frequency band. The benefits from service diversity accrue to customers irrespective of the frequency used to provide the service. There are currently substitute technologies performing some of the same functions as WBPR LMS in other areas of the spectrum, and thus new technologies and new LMS services can--and doubtless will--be developed for use in other frequency bands. The use of emerging technologies' spectrum for new PCS services, for example, is intended to spawn the widest possible range of services with as much technical flexibility as possible. As markets for location-based services expand, nothing prevents innovators from designing LMS technology for the 904-912 and 918-926 and other bands. The number of firms providing *service* in these particular bands should have no effect on the rate or direction of technical progress.

E. Summary of Benefits from Open Entry

The outcome of a competitive process in a market having unrestricted entry and non-exclusive spectrum licenses is different from that of an ordinary market. In ordinary markets, pursuit of profit induces firms to enter whenever a profitable prospect arises; thus above-normal economic profits are competed away. The result for consumers is an efficient number of firms in the market, prices consistent with economic costs, a reasonable amount of product differentiation and service diversity, and prudent amount of investment in research and implementation of new technology.

However, in order to implement non-exclusive licenses for WBPR LMS services in the 900 MHz band, some form of spectrum sharing would be required. And that sharing, in turn, would require coordination among firms that would reduce the desirable outcomes of the competitive process.

First, if market entry required only a non-exclusive license for a WBPR LMS system, the resulting number of firms in the market would not necessarily exceed the maximum of two firms that exclusive 8 MHz licenses would accomplish. Facilities and overhead spectrum requirements of WBPR LMS systems must be duplicated for every entrant. It has taken nearly twenty years for commercial WBPR LMS systems to come on line and it seems unlikely that increasing the fixed cost per unit of capacity for service providers would result in a more rapid development of this technology. In addition, even if a market could support four or eight firms, the fact that licenses are non-exclusive subjects potential entrants to a level of risk that would reduce any economic incentive to invest in facilities or new technology with the expectation of earning a return in the LMS market.

Second, even if non-exclusive licensing resulted in more than two firms per market, it does not follow that the market price would be lower than with two firms and co-channel separation. Coordination required for sharing would mitigate some of the benefits of having additional competitors, as would the relative sensitivity to price

from their level achieved with co-channel separation and two competitors in each market.

Third, even if each geographic WBPR LMS market became less concentrated under non-exclusive licenses, the resulting use of the spectrum would not necessarily be more efficient. While additional competitors may expand demand, it does not do so costlessly. There is no necessary relationship in economic theory between the number of firms in a product market and the rate and intensity of research and development, and there is evidence from the cellular market that many firms undertake research and development that do not participate in any geographic market as a cellular provider. Non-exclusive licensing greatly increases the uncertainty facing an investor which, all else equal, reduces the incentive to undertake research and development projects. ,

Finally, expanding the number of competitors in each geographic WBPR LMS market will not necessarily increase technological diversity and may actually reduce the scope of LMS services available to the public. Expanding the number of competitors requires sharing spectrum, which can be difficult or impossible for firms using different technologies and providing different services. LMS services such as personal location would not be feasible to perform in a WBPR LMS environment having less than 8 MHz of spectrum. In addition, there are many geographic markets and many other areas of the spectrum where innovative LMS services can be provided. Teletrac's proposal to institute co-channel separation and limit the number of WBPR LMS

does not restrict the ability of an entrepreneur to bring a new service or a new technology to market.

III. COSTS OF ADDITIONAL LMS COMPETITORS

In its NOPR, the Commission seeks comment on the feasibility of sharing the 904-912 and 918-926 MHz bands among different WBPR LMS providers.[27] If sharing is "immediately feasible," licenses would be granted for 8 MHz WBPR LMS systems on a non-exclusive basis in the 904-912 and 918-926 bands, and licensees would coordinate among themselves to avoid interference. Like the concept of interference, the concept of feasibility is governed by economic considerations. Whether customers are willing to pay that cost, and whether the benefits from having more than two WBPR LMS licensees in each market outweigh those costs are economic issues.

In this section, we examine the additional costs incurred to provide WBPR LMS service under a number of different assumptions about how that service is to be provided. The basic model we will use begins with a baseline cost per unit of capacity determined by the cost of each of two 8 MHz WBPR LMS systems occupying the 904-912 and 918-926 MHz bands respectively.[28] This baseline cost thus represents each firm's unit cost under the Teletrac proposal of co-channel separation and exclusive

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[27] NOPR, ¶ 22.

[28] The capacity of a system obviously depends on the particular WBPR LMS service being provided. A system used exclusively for auto theft recovery could serve many more subscribers than a system used for tracking school buses, because there is no need to track the location of any auto until it is determined to be stolen. For convenience, we will measure system capacity as the number of units that can be tracked during peak usage periods.

WBPR LMS licensing; increases in unit cost above this baseline thus represent the additional costs required to obtain the benefits discussed in Section II.

A. Costs of Serving Demand with More than One Supplier

For convenience, we will focus on one of the two 8 MHz bands that the NOPR proposes to devote to WBPR LMS services. Suppose a single firm using an 8 MHz WBPR LMS system could supply the market capacity of 100,000 units at some unit cost, say $100 per unit. If two firms serve the same geographic market instead of one, what would be the lowest possible average unit cost that the two firms could attain? To answer this question, we begin by listing the duplication of resources and facilities that is necessary to support two independent facilities-based providers of WBPR LMS service.

1. Duplication of Facilities

There are a number of categories of costs that are fixed with respect to the number of subscribers that must be duplicated if an additional firm enters the market: e.g., equipment and facilities, marketing and advertising, administration, etc. In particular, each firm incurs fixed costs of research and development which are likely to run into the tens of millions of dollars, and these costs are sunk in the sense that the firm cannot easily recoup them if it decides to exit from the WBPR LMS business altogether. Before a firm decides to enter the business, it must expect to be able to recover its variable costs as well as its fixed costs; no firm willingly enters a market with the expectation of losing money. Hence, the market price--in equilibrium--should

be higher (all else equal) with more firms in the market because it must recover the combined fixed costs of all firms in the market.

In order for two WBPR LMS systems to serve the same geographic area, each firm must buy or lease facilities and equipment to

- broadcast signals that can be received by all mobile units in the geographic area,
- receive signals from mobile units at as many different locations as are necessary to obtain sufficiently accurate location estimation by mulitlateration, and
- link each receive site with a central computing facility that performs the multilateration calculations.

Each of these facilities must be installed for the system to serve a single subscriber, and all of these costs are roughly independent of the number of subscribers or the number of vehicle locations performed. The cost per unit of capacity of these fixed facilities will thus double if two firms serve the market instead of one.

In addition, each potential WBPR LMS entrant must expect to be able to price sufficiently high above its variable costs to recover its cost of developing or licensing a WBPR LMS technology. From Teletrac's experience, the one-time costs of research and development are in excess of $60 million with additional tens of millions likely to be incurred. Conservatively amortizing this sunk cost over 10 years with a 10 percent discount rate would add about $10 million to the annual cost that must be covered for entry to be profitable. While the $10 million annual cost can be spread over each geographic market, it is still quite large relative to operating expenses, and a potential entrant must have a reasonable prospect of recovering both fixed and variable costs before it can be induced to enter the WBPR LMS business.

2. Duplication of Spectrum Overhead

In addition to fixed costs of towers and transmitters, WBPR LMS systems also use a certain amount of capacity in the form of overhead transmissions to calibrate the system and to establish, monitor, and re-establish system synchronization. Using current technology, such transmissions for an 8 MHz firm comprise between 5 and 15 percent of its current system capacity. Two firms sharing the 8 MHz would each require the same amount of overhead capacity as the single 8 MHz firm, so that doubling the

Table 1
Capacity of WBPR LMS Systems

		Two Firms	Four Firms	Eight Firms
Capacity per Firm	effective nominal	200,000 250,000	75,000 125,000	12,500 62,500
Total Capacity	effective nominal	400,000 500,000	300,000 500,000	100,000 500,000

number of firms would double the required total amount of overhead capacity. Assuming overhead capacity to be 10 percent of the capacity of a single firm, increasing the number of systems in a market from two to four causes the effective capacity to fall by 25 percent.

Table 1 shows the effect on capacity of increasing the number of firms serving the same geographic market. Since total capacity is 500,000 subscribers, each system will require 50,000 units of capacity for overhead. Two 8 MHz WBPR LMS systems with a combined nominal capacity of 500,000 subscribers would thus require 100,000 units of capacity for overhead costs, permitting them to serve 400,000 subscribers. Each of four firms that together would have a nominal capacity of 500,000 would be able to serve 75,000 subscribers and would devote 50,000 units of capacity to overhead transmissions. Effective total capacity would thus fall from 400,000 to 300,000 as two additional firms enter the market, a reduction of twenty-five percent.

This phenomenon is precisely analogous to the effect of fixed costs of facilities discussed in the previous Section. If two small systems serve the same demand that one large system serves, each system requires its own facilities, and that requirement--all else equal--makes the unit cost of the two systems higher than that of a single large system. Here, each system requires calibration and synchronization transmissions whose capacity is approximately independent of the total capacity of the system. It is roughly twice as expensive to keep two small, independent systems calibrated and synchronized as to synchronize and calibrate a single system having twice the capacity as the small systems. We can combine these effects with the duplication

of facilities effect discussed in the previous section. There, operating cost per unit of capacity was estimated to be 47.5 percent higher if demand were served with 4 firms rather than 2 and 142 percent higher if demand were served with 8 firms instead of 2. Now, operating cost per unit of *effective* capacity is 96.6 percent higher in the 4 firm case than in the 2 firm market and 870 percent higher with an 8 firm market than with a 2 firm market.

Note that this source of additional costs incurred with additional competitors in the market has nothing to do with the method (if any) by which the firms coordinate their use of the spectrum. Also, the additional cost is incurred whenever an additional firm enters the market; the cost is independent of the size of the market actually served by the entrant.

B. Inefficient Division of Bandwidth

Another reason why unit capacity costs can increase with the number of competitors is distinct from the previous case which depended upon duplication of facilities and overhead capacity requirements. As discussed in Section IX-B of the Pickholtz Study, division of bandwidth among competitors is wasteful of spectrum, since the accuracy of measurement is inversely proportional to the square of the bandwidth. Suppose 8 MHz were divided between two competitors, giving each 4 MHz. This allocation would permit 4 WBPR LMS competitors in each geographic market, but it would be an inefficient use of spectrum because the capacity of the system--for a given level of accuracy--is directly proportional to the square of the bandwidth. If the nominal capacity of the single 8 MHz firm is 500,000 units, two 4 MHz firms would

together have a nominal capacity of 250,000 units and the total capacity of four 2 MHz firms would be 125,000 units. Thus doubling the number of competitors by splitting each firm's bandwidth in half has the effect of at least quadrupling the fixed costs per subscriber.[29]

Note that this source of additional cost is independent of the fixed costs of facilities and of overhead calibration and synchronization capacity. The decision to

Finally, for given accuracy and power, reduction in the bandwidth available for each licensee would reduce the financial viability of the service. Our previous discussion assumes that the effect of granting non-exclusive licenses for WBPR LMS service would be to increase the likely number of competitors in each market. Now the decision to commit funds in the form of sunk costs to a new LMS service requires that the investor have an expectation that the investment will return an adequate profit to compensate for the risk. Licensing on a non-exclusive basis increases the uncertainty associated with the project. Uncertainty remains regarding technological parameters and public demand for the various services the network can provide. However, the prospective entrant must also forecast likely returns (and their associated probabilities) in scenarios with different numbers of competitors. As we have shown above, the cost to serve a given number of WBPR LMS subscribers depends critically upon the number of independent systems that are used to provide service.

C. Costs of Coordination

The cost effects discussed so far have ignored the problem of coordination of different firms providing service in the same geographic area. Coordination of spectrum use can entail direct costs because resources must be expended to define and monitor sharing arrangements, and it can impose indirect costs in which unit costs of the WBPR LMS services are driven upward by the need to coordinate spectrum use. We show first that uncoordinated use of the same bandwidth in the same geographic area by two competing WBPR LMS systems is not economically feasible. We then

examine the costs of two alternatives to uncoordinated sharing: time division and frequency division sharing methods.

1. Uncoordinated Sharing is Economically Impractical

It should be clear from Pickholtz Study that WBPR LMS systems have a number of characteristics which make it difficult for competitors to set and maintain sharing rules even though the existence of such rules is in each competitor's own interest. First, unlike narrowband systems, WBPR LMS systems determine the location of a mobile target that could be anywhere in a coverage area. The ability to serve a wider coverage area (holding accuracy constant) is a competitive advantage, and one would expect to see firms compete by offering wider-area, higher accuracy services.[32] Thus a critical economic difference between WBPR LMS services and narrowband LMS services is that the geographic areas served by competing WBPR LMS competitors must overlap. Harmful interference is thus inevitable when WBPR LMS systems compete using the same frequency.

Second, uncoordinated sharing using signal detection methods is impractical for WBPR LMS services. The technology of pulse measurement for location determination is not suited for detecting the presence of competitors' transmissions to avoid harmful interference because the short duration of pulses makes monitoring too inaccurate to be practical, in the sense that an intolerable level of harmful interference would result from the use of this method. Thus the uncoordinated sharing techniques

[32]For some LMS services, it is conceivable that accuracy in a small geographic area (e.g., midtown Manhattan) could be more important than wider geographic coverage.

used for other services (e.g., paging and air-to-ground telephone service) is not feasible for WBPR LMS services.

Finally, two competing WBPR LMS systems cannot use the same frequency in the same geographic area without some kind of sharing to avoid interference. Consider the investment opportunities faced by potential WBPR LMS suppliers under a non-exclusive licensing plan. Each investor must consider possible antenna locations to provide uninterrupted coverage throughout the market. Since there are a limited number of sites that can efficiently cover the metropolitan area, the likelihood of locating competing base stations on the same or nearby towers is high. According to the Pickholtz Study, at 43-44, the cost of overcoming interference from any competitor's transmissions makes coexistence with a co-channel LMS station within one mile economically infeasible, as it would raise fixed costs by at least 1000-fold, reduce system capacity by a factor of one million, or increase the required bandwidth by a factor of 1000. An investment in such a system would probably not be profitable.

Moreover, any attempt to engineer a system to overcome the harmful effects of a competitor's WBPR LMS system would simply trigger a retaliatory competitive response. One system's signal is another system's noise, when they attempt to use the same band of spectrum in the same geographic area. If one firm increases its power, the duration of its pulses or the number of its base stations, its service improves, and the service of its competitors deteriorates. In a competitive market, the firm benefits from both effects, which gives the firm an incentive to over-engineer its service.[33]

[33]Note that this incentive is inefficient even if no other firm retaliates because additional costs are incurred and no customers benefit from the reduction in quality of rival firms' services.

In addition, since the firm's competitors can make the same adjustments, all firms in

2. Time and Frequency-Domain Sharing Impose Significant Costs

The question remains whether or not sharing frequency (with no coordination in time) or sharing time on the same frequency would be feasible or immediately feasible in an economic sense and what the costs of such sharing might be.

The costs of frequency-sharing were treated in Section III.B, where an iron law of signal detection means that unit costs of capacity are inversely proportional to the square of the bandwidth of the system. In addition, the sharing of frequency requires sharing of information about the technology of the system and the services it supports as well as a certain communality of technology across firms.[34] Such requirements would mitigate the benefits that one would hope to obtain from inducing additional firms to enter each geographic market. In particular, frequency sharing costs include the reduction in service and technology diversity imposed by the technical requirements of sharing. Finally, spectrum sharing requires well-defined protocols that may depend upon knowing in advance the number and identity of firms participating in the sharing agreement. Spectrum sharing in such cases sacrifices the benefit of open entry which reduces the probability and profitability of collusion by increasing the number of competitors. Because extensive coordination is required to share spectrum for these services, increasing the number of WBPR LMS competitors in a geographic market may increase the ability of the sharing partners to overtly or tacitly collude to raise the market price.

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[34]See Dr. Jackson's Affidavit (op. cit.) ¶ 12.

Time-division sharing does not entail the same inefficient use of the spectrum identified above for bandwidth sharing. If two firms could costlessly coordinate use

In addition, some of the intended benefits from competition require the absence of entry barriers so that firms in the market are disciplined automatically by the tacit threat of easy entry if supra-normal profits emerge. Thus time-division sharing might increase the number of participants in the market (albeit at some cost) but it also retains barriers to entry in the market so that whatever competitive pressure that one might anticipate to emerge from open entry into geographic WBPR LMS markets will not emerge from a time-division sharing scheme.

D. Costs Associated with Higher Market Risk

The analysis to date has tried to identify, estimate, and compare the costs and benefits from attempting to operate WBPR LMS services on a non-exclusive basis. While time-division or spectrum sharing is feasible for some services, our analysis shows that it is unlikely that more than two firms can profitably serve the same WBPR LMS market on a shared basis. What these calculations do not show, however, is the added effect on system costs due to the added uncertainty associated with investment in research and development and in the cost of sunk facilities because important features of the market are unknown at the time investment must be committed.

A particularly perverse source of risk derives from the effect of the number of firms in a market subject to any form of spectrum or time sharing on the unit capacity cost of each firm. Because the number of firms applying for a license in each geographic market would affect the cost of any service provider in that market, a significant component of the firm's cost structure would be unknown to the firm's investors when capital must be committed. Moreover, this source of cost uncertainty

is not one that the firm can do anything about; reducing its costs or hedging against changes in the prices of inputs cannot reduce the firm's exposure to this type of risk. Such uncertainty makes it unlikely that additional firms would voluntarily enter the market if WBPR LMS systems were required to share frequency.

Non-exclusive licensing gives rise to other sources of uncertainty. If the sharing arrangements were too imprecise to forecast accurately the amount of interference in the band, designers would be unable to optimize systems for the environment, and investors would run the risk of building systems that ex ante were too fragile (and too inexpensive) or too robust (and too expensive) for the actual environment.

The costs of additional uncertainty in terms of required risk premia to induce investment are difficult to quantify. Nonetheless, any regulatory proposal that increases the ability of actual and potential competitors to predict their ultimate costs and capacities will improve the climate for investment in facilities and in new technology. Whatever else its merits, the least uncertain regulatory environment is co-channel separation.

E. Resale Competition

It is apparent from the analysis above that duplication of physical facilities and overhead transmission bandwidth associated with additional competitors raises significantly the total cost per subscriber of WBPR LMS systems. It is worth noting that some--but not all--of the benefits of open entry can be achieved without incurring these costs by permitting and encouraging resale of the two 8 MHz systems.

Of course, resale competition does not directly reduce the market power (if any) derived from owning one of two WBPR LMS facilities in a geographic market.[35] On the other hand, resale can mitigate some of the possible disadvantages of limiting entry into the facilities market. Large resellers may be able to provide countervailing monopsony power, particularly if they are naturally more efficient or better suited to the retailing function than is the facilities-based provider. Resale also restricts the amount of price discrimination on the part of the facilities owners because resellers can arbitrage away differences in price (e.g., bulk discounts) that might not be based on differences in costs. Finally, resale does eliminate any potential market power in the retail function of WBPR LMS services, so that ancillary services (such as special billing arrangements) will be provided to customers at competitive prices irrespective of the degree of competition in the LMS services market.

IV. Summary

The NOPR tentatively concluded that co-channel separation for WBPR LMS systems was not in the public interest because it would foreclose benefits that the

degree of uncertainty associated with the future cost of service, so that service prices could rise, rather than fall, and that the rate of investment in facilities and in research and development could slow.

From an economic perspective, it is unlikely that non-exclusive licensing will produce the intended benefits. Operation on a non-exclusive basis is not likely to increase the equilibrium number of firms in the market because such operations increase both costs and uncertainty. Increasing the number of competitors would not, in turn, reduce the price of LMS services because (i) there are already reasonable substitutes for LMS services, and (ii) the technical requirements of providing service in a shared environment reduce whatever competitive benefits might flow from an increase in the number of WBPR LMS providers in a geographic market. Neither economic theory nor empirical evidence supports the notion that an increase in the number of potential WBPR LMS providers in a geographic area would lead to a faster rate of technical progress. Finally--and most importantly--evidence from the cellular market suggests that the large number of different geographic markets and the presence of an equipment market means that the number of firms in each geographic service market has no effect on research or technological diversity.

The accommodation of additional competitors in each WBPR LMS market raises total costs of serving a geographic market significantly. Facilities must be duplicated for every additional facilities-based carrier; based on accounting data from a current service provider, such fixed costs would raise industry costs by between 30 and 60 percent as the number of firms increases from two to eight. More significantly, bandwidth is required to calibrate and synchronize each system, so that

proliferation of competitors rapidly increases the unit cost of usable capacity; the presence of one additional competitor would increase unit capacity costs by as much as 33 percent, and the market would be unable to function with four or more competitors. Finally, splitting or sharing frequency among competitors reduces the total capacity of the system and thus increases unit capacity costs. Splitting one bandwidth between two competitors effectively doubles the total system capacity cost. Where such duplication costs are high, some of the benefits from vigorous competition can be derived from open entry in the resale market. Nonetheless, while it is difficult to obtain hard evidence concerning the costs and revenues of firms in this emerging technology, it should be clear that imposing additional costs of this magnitude will retard investment and development of WBPR LMS technology.

Coordinating frequency use for these services also sacrifices some of the benefits that non-exclusive licensing was intended to produce, including price competition among sharing partners, service and technology diversity, and competitive benefits from open entry. In addition, non-exclusive licensing greatly increases the uncertainty facing investors in these markets, leading inevitably to a reduction in the development of WBPR LMS markets and to a slowing of technical progress.